



Article

Temporal Relationships of Breeding Landbirds and Productivity on a Working Landscape

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Simple Summary: Vegetation greenness has been linked to important life events for birds, particularly during breeding season when they need more food for young as well as energy and shelter to escape predators and attract mates. This study examines how vegetation greenness affects individual bird numbers and species numbers across breeding seasons in South Texas, USA. We gathered bird data through on-the-ground surveys and vegetation greenness through aerial imagery. Our findings suggest that the months prior to peak breeding season may be most influential in terms of greenness. With this information, we can better predict and plan for impacts of future environmental changes on bird populations on rangelands.

Abstract: The Normalized Difference Vegetation Index (NDVI) is a measurement of landscape “greenness” and is used as a proxy for productivity to assess species distributions and habitats. Seasonal levels of productivity have been strongly related to avian population dynamics, suggesting dependence upon biomass production for completing annual life cycle events. The breeding season is a critical component of the avian life cycle that involves higher nutritional requirements to feed young, avoiding predators, and attracting mates. Our objective was to determine how the NDVI affects avian abundance and richness across breeding seasons with varied rainfall in South Texas, USA. Breeding bird point-count surveys were conducted, and MODIS Terra NDVI data were collected. We observed both positive and negative effects between May and June avian abundance, richness, and the NDVI depending upon the year (i.e., wet or average rainfall) and NDVI values in the months prior to (i.e., April) and during the peak of breeding season (May), with no significant effect of the NDVI in June, suggesting the months prior to peak breeding season may be most influential. This information can aid land management recommendations and better predict how environmental changes like rainfall may affect avian dynamics on a landscape for both wildlife and domestic animals.

Keywords: avian abundance; avian richness; biomass; breeding birds; NDVI; rangelands



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1. Introduction

Rangelands are the most common working landscape in the United States and globally [1]. They are an important ecosystem for grazing and browsing of domestic livestock and wildlife [2,3]. While they provide goods and services to humans, such as animal production, recreational opportunities, and water, it is challenging to plan and sustain healthy rangelands that benefit animals and humans alike [2,4]. Efforts to maintain a healthy ecosystem are further complicated by fluctuations in environmental conditions that affect vegetation that support both domestic and wild species. Extreme rainfall [5,6] or drought [7,8] can severely affect plant communities required by terrestrial species as food and/or cover resources. This variability creates difficulties in the management of rangelands for the benefit of all.

Vegetation can strongly influence animal movement and distributions; therefore, it is imperative to assess how environmental changes can affect wildlife species [9]. Identifying and managing important wildlife habitats that support diverse vegetation communities and ecologically important or threatened species have been of significant concern for many years, particularly with migratory birds [10–13]. Changes in the environment related to available resources such as vegetation have affected avian population dynamics [14,15]. Thus, avian presence may be a strong indicator of ecosystem functions such as seed dispersal, pollination, and pest control while also providing reliable measures of changing environments [16–18]. Birds are considered bio-indicators and can be used to assess the health of ecosystems since they respond well to changes in their environment [18]. Climate change has also become a challenge over the last few decades, causing population re-distributions, shifts, and other effects on avian species [19–23]. These responses by birds to environmental or climatic changes suggest the integration of environmental metrics and landscape data into studies to improve predictions of the effects of these changes on avian species.

Climate change impacts of concern include the increasing variability, number of events, and total rainfall and its effects on terrestrial ecosystems [24–26]. The most important influence on vegetation dynamics in arid and semiarid rangelands is rainfall [2]; rainfall has a direct impact on vegetation greenness and biomass productivity, which can be measured with the Normalized Difference Vegetation Index (NDVI) [27,28]. Values of the NDVI are commonly used as a surrogate for vegetation greenness, biomass productivity, or energy [28,29] and are available from remote sensing platforms that capture red and near-infrared bands (e.g., MODIS) [9,30,31]. Approaches, including the NDVI, have been used to assess species distributions and their habitats and can be positively linked to species evenness, richness, and abundance across a variety of taxonomic groups and settings, including urban areas [28,32–36]. Because of the usefulness of the NDVI as a measurement on the landscape and its relationships with biodiversity, it can be used as a tool to assess how environmental fluctuations affect avian populations [37].

Previous research suggests that when the NDVI is evaluated during spring and summer months at regional or larger scales, it is a reliable indicator of species richness [38]. Although the NDVI has been extensively used to assess relationships with avian populations during the breeding season and annually, minimal research has considered the months prior to the breeding season and their relation to bird abundance and richness on working landscapes [39]. Hunt et al. (2023) [39] utilized monthly productivity beginning in March to determine spatial drivers of farmland and woodland bird diversity and also recognized the limited research using the monthly NDVI. They [39] found that April and March NDVIs were key for farmland birds, whereas May and June were important for woodland birds. This may be important for identifying the needs of habitat-associated bird species, but more generally, including also the spatial variation of the NDVI, it can

be a better predictor of bird richness [38]. Capturing the spatial variation of productivity across a landscape can highlight the differences in habitat conditions available for birds. Conditions across the breeding season decrease over time often leading to a decline in reproductive success [40]. Therefore, high-quality conditions in breeding areas prior to the start of breeding season can allow for early reproduction and/or potentially better survival of offspring [40,41].

This study took place in a region experiencing subtropical subhumid-to-semiarid regimes of high temperatures but also high humidity and occasional frosts [42]. During the years of 2014–2016, the landscape recovered from a two-year drought with a high amount of precipitation exceeding what had been seen in the previous decade. With this environmental variability, our objective was to determine how landscape productivity affects avian abundance and richness across breeding seasons. We expect that high biomass production would lead to positive impacts on bird abundance and richness and that these relationships would be observed over the years of the study. With a more productive landscape, it is anticipated that the abundance and richness of birds would be greater because they rely on productive, dense vegetation for shelter, nesting, and food during breeding [12,43,44].

2. Materials and Methods

2.1. Study Area

The East Foundation's El Sauz Ranch is located west of the town of Port Mansfield in Willacy and Kenedy Counties along the South Texas coast, USA (Figure 1). The ranch is 11,082 ha in size and contains 37 km of roads, 30.6 km of creeks, and 254 ha of water bodies. El Sauz is part of the Gulf Coast Prairies and Marshes ecoregion [45,46] with dominant vegetation including seacoast bluestem (*Schizachyrium scoparium*) and gulf dune paspalum (*Paspalum monostachyum*), honey mesquite (*Prosopis glandulosa*) and granjeno (*Celtis pallida*) parks and live oak woodlands (*Quercus virginiana*), and occasional gulf cordgrass (*Spartina* spp.) prairie patches and wetlands [45,47,48].

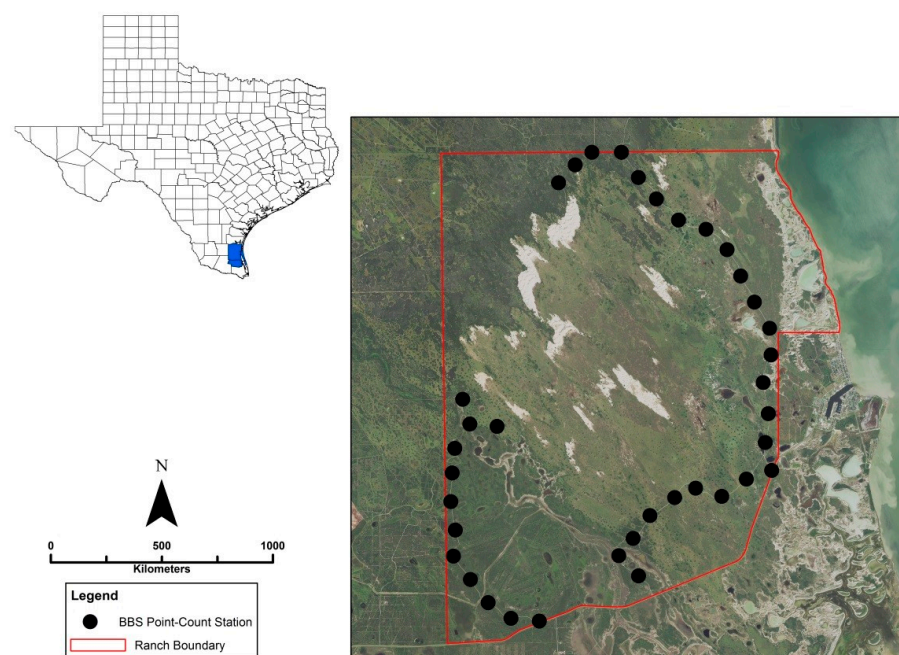


Figure 1. East Foundation's El Sauz Ranch is located within Willacy and Kenedy counties, Texas, USA, along the south Texas coast. Breeding bird survey (BBS) point-count stations (37) are illustrated with black dots and were used for the length of this study from 2014 to 2016.

This study took place from 2014 to 2016, where average daily temperatures in each year for neighboring Port Mansfield, TX, USA, were 22.2 °C, 22.7 °C, and 24.1 °C, respectively [49]. To categorize each year of this study based on rainfall during bird breeding season, total annual rainfall for each year was calculated from the end of one breeding season to the end of the next breeding season (e.g., July 2013–June 2014) (Figure 2). Total rainfall was 615.2 mm (2014; recovery, average rainfall), 1121.7 mm (2015; wet), and 697.5 mm (2016; average rainfall), with 2014 considered a recovery year following a drought period (2010–2013). The years of study and respective total rainfall are shown with red arrows in Figure 2.

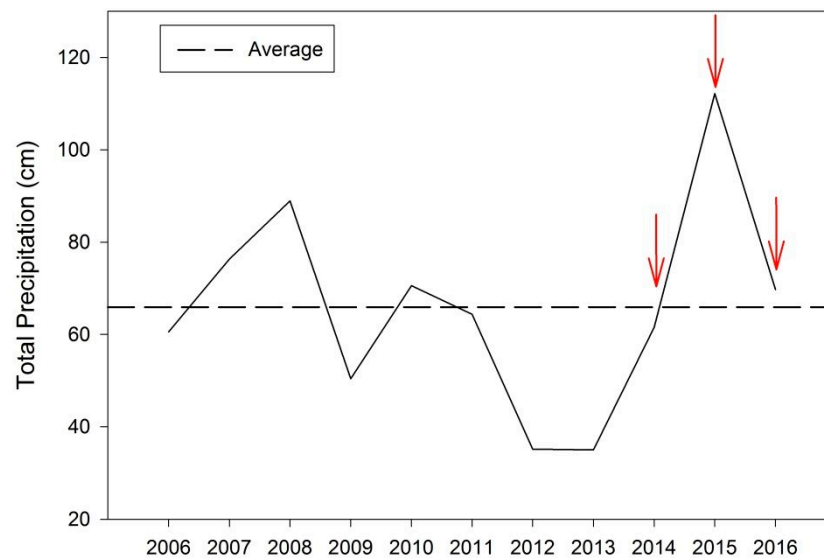


Figure 2. The total annual precipitation received by Port Mansfield, Texas, USA, from 2006 to 2016. Precipitation is shown for a ten-year span to display fluctuations in annual precipitation and drought beginning in 2010. This study took place from 2014 to 2016 and is indicated by the red arrows, with 2014 considered a recovery, post-drought year that received average precipitation. The year 2015 was above average, and 2016 was an average year. Average annual precipitation is depicted by the dashed line.

2.2. Data Collection and Analysis

Breeding bird surveys (hereafter BBS) were conducted by one observer with routes sampled once per month in mid-May and mid-June in the years 2014, 2015, and 2016 at the peak of breeding season to capture resident birds and birds that have migrated in for breeding. Survey driving routes were modeled after the United States Geological Survey's official North American Breeding Bird Survey routes. A total of 37 point-count stations were established along 29.6 km, with one point every 800 m [50] (Figure 1). When establishing driving routes, we used most primary and secondary roads to maximize area and habitats surveyed. Surveys were not conducted in poor environmental conditions (e.g., low visibility, high wind speeds (>20–29 km/h), constant rainfall) [51].

Surveys began 30 min before sunrise and were completed within 6.5 h [50]. Counts were conducted for three-minute periods upon arriving at the point-count station. The vehicle was turned off, and the observer stepped outside of the vehicle to record the number of individuals of species identified by sight and/or sound within a radius 200 m from the vehicle location. Vegetation on the ranch is thick, and detection can decrease as coverage increases [52], preventing birds from being heard or seen. Therefore, we adjusted our survey radius within the national protocol of 400 m following Hurlbert (2004) [53] to improve our ability to see or hear birds. Data from BBS are an index of avian abundance and diversity, not a complete count or estimate of actual density [50]. For our purposes,

abundance was considered the total number of individuals observed and heard at each point-count station for each month of surveys. Total number of birds seen and heard was used as an abundance index, which is an incomplete and unadjusted count to determine trends and not an estimate of population size [54,55]. The number of species observed and heard at each point-count for each month of surveys is documented as richness per month of surveys. Species with low encounter rates were removed from analysis [53,56].

We acquired monthly NDVI datasets (250 m spatial resolution, 16-day temporal resolution) from MODIS Terra (MOD13Q1 NDVI) images from the United States Geological Survey Earth Explorer [57] for April, May, and June of 2014–2016. Monthly datasets were used, as previous research has shown that annual values of the NDVI may not be a strong predictor of bird abundance or richness for surveys that take place for only a small portion of the year [55,56]. The NDVI can be calculated from the reflectance of the near-infrared and red portions of the electromagnetic spectrum and is represented by a ratio of the difference of the two spectral bands divided by the sum of the two spectral bands [56,58]. Higher NDVI numbers (e.g., closer to +1) signify thicker, greener vegetation with more photosynthetic activity, and negative values (e.g., closer to −1) suggest vegetation absence [59,60]. We pre-processed imagery using the HDF-EOS to GeoTIFF Conversion Tool (HEG) to change the file format (Raytheon Company, Riverdale, MD, USA) and imported into ArcMap 10.4 (ESRI, Redlands, CA, USA). NDVI pixel values were extracted for each image prior to (April) and during the bird survey period (May and June) at each of the GPS coordinates for the 37 point-count stations using the Extract Values to Points tool.

We used a generalized linear mixed model (GLMM) to determine the effects of NDVI on avian abundance and richness. Abundances (number of individuals per survey month) and richness (number of species per survey month) from May and June were used assuming a negative binomial distribution for a count response variable and to protect from overdispersion (e.g., excessive zeros). To account for repeated measures over the same locations (37 point-count stations; random effect) across time (2014–2016), we used a first-order autoregressive variance-covariance structure [61]. The first models included abundance or richness as the dependent variable and the independent variables of NDVI values per month (April and May), each year of the study (2014–2016), and all possible interactions as fixed effects. Although we initially included NDVI values for June in the model, data were found insignificant and removed. Further analysis included the influence of NDVI per month at low, medium, and high levels on the avian metrics (abundance, richness) separately. Significant relationships among variables were considered below the alpha level of 0.05, and near-significant relationships are recognized between the alpha levels of 0.05 and 0.10. Statistical analyses were conducted in SAS 9.4 (SAS Institute, Inc., Cary, NC, USA).

3. Results

There was a total of 900, 1273, and 1172 birds counted in 2014, 2015, and 2016, respectively (Table S1). Across all three years, there were 84 unique species detected (Table S2). There was an average of seven species detected in 2014, nine in 2015, and nine in 2016 across all point-count stations. The most common species detected were Northern Mockingbird (*Mimus polyglottos*), Northern Bobwhite (*Colinus virginianus*), Mourning Dove (*Zenaidura macroura*), and Bewick's Wren (*Thryomanes bewickii*).

3.1. Avian Abundance

The results of the analysis on avian abundance showed a significant three-way interaction between the April NDVI, May NDVI, and year ($df = 61$, $F = 4.12$, $p = 0.021$) for

the month of May. The same was seen for the month of June surveys where there was a significant three-way interaction between the April NDVI, May NDVI, and year ($df = 63$, $F = 6.76$, $p = 0.002$).

The first year of average rainfall following a drought period in South Texas was in 2014 (Figure 2). There was minimal effect of April and May NDVI levels on May bird abundance; however, a higher abundance is observed at a low May NDVI (Table 1). Bird abundance in June fluctuated based on high and low April and May levels of the NDVI.

Table 1. Results of low, medium, and/or high April and May NDVI effects on avian abundance for May and June for three consecutive years, 2014, 2015, and 2016. Near significant ($0.05 < p < 0.10$) and significant ($p < 0.05$) effects are presented.

Year	Survey	NDVI Month	NDVI Level	Effect	DF	t Value	p
2014	May	May	Low (0.23)	+	61	1.73	0.0890
			High (0.65)	−	63	−2.73	0.0083
	June	April	Low (0.35)	+	63	2.11	0.0385
			High (0.65)	+	63	2.49	0.0155
			Low (0.23)	−	63	−2.49	0.0153
2015	May	April	Medium (0.61)	+	61	3.15	0.003
			High (0.76)	+	61	3.21	0.002
			Low (0.50)	−	61	−2.20	0.032
	June	April	Medium (0.61)	+	63	2.82	0.006
			High (0.70)	−	61	−2.01	0.049
2016	May	April	High (0.70)	−	61	−2.01	0.049
			Low (0.25)	+	61	2.16	0.034
	June	April	Low (0.35)	+	63	1.85	0.069
			High (0.70)	−	63	−2.48	0.016
			Low (0.25)	+	63	3.47	0.001
	May	Medium (0.55)	+	63	1.80	0.076	

Note: Green background signifies a positive effect and red indicates a negative effect.

Shifts in NDVI levels to primarily over 0.5 were evident in 2015, which is why this year is classified as a wet year (Figure 2). Negative effects on bird abundance in May was observed at a low NDVI in May, yet positive effects on bird abundance were observed across both survey months with mid-to-high levels of the April NDVI (Table 1) for May surveys and with only a mid-level April NDVI for June surveys.

In 2016, rainfall on El Sauz was average following the heavy rainfall in the previous year (Figure 2). NDVI values were similar to May 2014, ranging from 0.2 to 0.7. At high April NDVI levels, negative effects on bird abundance were observed, even with a high NDVI in subsequent survey months (Table 1). Positive effects on May and June bird abundance were observed even though the May NDVI was low across both survey months.

3.2. Avian Richness

Analysis on avian richness showed a significant two-way interaction between the April NDVI and year ($df = 63$, $F = 2.43$, $p = 0.097$) for the month of May. For the month of June, there was a significant three-way interaction between the April NDVI, May NDVI, and year ($df = 63$, $F = 4.62$, $p = 0.013$).

In 2014, there was very little effect of April and May NDVI levels on bird richness in May; however, positive effects on richness were nearly significant at low- and mid-levels of the May NDVI (Table 2). Low- and mid-level April NDVIs had a negative effect on June

bird richness. The same is seen with a low May NDVI yet positive effects on June bird richness with medium and high May NDVI levels.

Table 2. Low, medium, and/or high April and May NDVI effects on avian richness for May and June for three consecutive years, 2014, 2015, and 2016. Near significant ($0.05 < p < 0.10$) and significant ($p < 0.05$) effects are presented.

Year	Survey	NDVI Month	NDVI Level	Effect	DF	t Value	p
2014	May	May	Low (0.23)	+	63	1.90	0.062
			Medium (0.55)	+	63	1.68	0.098
	June	April	Low (0.35)	−	63	−2.99	0.004
			Medium (0.50)	−	63	−2.59	0.012
		May	Low (0.23)	−	63	−1.98	0.052
			Medium (0.55)	+	63	2.43	0.018
2015	May	April	High (0.65)	+	63	3.11	0.003
			Medium (0.61)	+	63	2.69	0.009
			High (0.76)	+	63	2.21	0.031
	June	April	Medium (0.61)	+	63	2.90	0.005
	May	April	High (0.70)	−	63	−2.00	0.049
2016	May	May	Low (0.25)	+	63	3.01	0.004
			Medium (0.55)	+	63	1.95	0.056
	June	May	Low (0.25)	+	63	3.32	0.001
			Medium (0.55)	+	63	3.31	0.076

Note: Green background signifies a positive effect and red indicates a negative effect.

The wet year of 2015 did not have as much of an impact on bird richness in either survey month. Positive effects on species richness were observed only in May at medium to high levels of the April NDVI (Table 2) and in June at a medium level of the April NDVI.

Returning to an average rainfall year in 2016, species richness in May was negatively influenced by a high April NDVI (Table 2) yet positively influenced by low and medium May NDVI levels. Low and medium May NDVIs positively influenced June bird richness.

4. Discussion

The effects of the NDVI on avian abundance and richness were complex across time and should be considered when assessing the effects of environmental variables on avian dynamics. These results partially support our expectations that high bird abundance and richness would be influenced by a high NDVI. We observed both positive and negative relationships between avian abundance and richness and the NDVI depending upon the year and NDVI values in the months prior to and during surveys. The influence of a higher NDVI on abundance later in the breeding season was much more evident in the recovery year from the drought in 2014 and not so influential in an average year. However, in a wet year, a higher NDVI prior to the peak of breeding season was much more influential on abundance. It also appears that there was a lag in positively influencing species richness, as birds progressed through the breeding season in response to a higher NDVI in years of average rainfall. Studies have shown that species may not be tracking changes in spring greening due to changes in climate [62,63], which can be particularly detrimental to migratory birds, whose arrival may not coincide with the boost in resources. The positive effects on species richness were much more pronounced before the peak of the breeding season during a wet year, which may align with favorable conditions

for the birds in the environment prior to the reproductive season. This emphasizes the importance of differences in local conditions and geographical variations that are not always applicable to regional conditions and/or global occurrences [64]. Future investigations should incorporate locally specific environmental factors in their work, which can apply to different landscapes and assist in gathering information that is appropriate for the scale of interest.

An assessment of environmental conditions prior to the collection of field data is critical to understand how populations may be impacted. For instance, the month prior to the peak of breeding season (i.e., April) was a contributing factor in the relationships we observed during the peak of breeding season between the number of birds and species and NDVI levels. Biomass productivity in the pre-breeding season appears to be important because this may be a phase during which birds may seek to breed by finding mates and begin raising young. Hahn and Silverman (2006) [65] showed that migratory birds will select their habitat prior to breeding. However, Betts et al. (2008) [66] claimed that conditions during pre-breeding season, which can enhance reproductive success, may not be obvious upon arrival (i.e., green vegetation, nesting cover), leading birds to select unsuitable or lower-quality locations. This may be what happened in 2014, where most sampling locations represented medium levels of the NDVI. To our knowledge, one other study has considered the months prior to the breeding season and their relation to bird diversity and richness during the breeding season on farmlands and woodlands [39]; however, the study did not focus on abundance, and the landscape in our study was much different. Previous work on avian abundance or richness and its relationship with the NDVI has been limited to June only [32,35,53,56,58], annual values [56,67], annual averages [28,38], and seasonal averages [38]. Our study captured the NDVI during the time in which it is important for breeding birds and prior to and during the breeding season, where resources are most important for the parents and offspring coming in the next generation. The mismatch in the temporal scale of the NDVI and field collected data [52,53] appears to be an oversight of previous investigations on NDVI effects on avian dynamics and should be considered in future studies, especially when evidence exists of late bird breeding phenology when compared to the timing of vegetation green-up [68].

In addition to the NDVI, other factors may contribute to the number and distribution of birds observed. Even with an average year of rainfall (i.e., 2016) and a higher NDVI, positive relationships with avian abundance and richness were not the only relationships observed. This may suggest that an optimum range of productivity levels may be sought by birds on the landscape; in other words, birds may seek a range of productivity levels and not necessarily those that are high, which was observed in 2015. Another option is that birds may show behavioral plasticity and are capable of surviving and reproducing under a range of productivity levels. Researchers have found that birds may move or shift locations during the breeding season, which may be a result of timing for these surveys [69,70]. This may influence our findings since surveys occur only once per month, essentially capturing one moment in time, and it is possible that areas may be more productive at that time than the next month's visit, shifting outcomes of the survey. Betts et al. (2008) also found that naïve individuals who initially occupy sub-optimal sites may move onto higher quality sites when available. These higher quality sites may be those with a higher NDVI. In addition, these naïve individuals may be filling areas considered sub-optimal habitat in comparison to experienced individuals in greener, more optimal areas (i.e., high NDVI), which has been shown to improve reproductive success in some species [71]. In contrast with our study, McFarland et al. (2012) [35] suggested that the NDVI may be more appropriate for detecting habitat needs for individual species rather than overall species richness and NDVI relationships. However, this may explain annual differences we observed in richness

when comparing average to wet years, as wet years can provide plentiful resources that may be able to accommodate more species needs compared to dryer years. Furthermore, our initial exclusion of the June NDVI may be indicative of the phenology of the birds on the ranch. Previous research has found that 111 species of North American landbirds were shifting breeding phenology earlier due to a warming climate [63]. Additional research on individual and species use of sites varying in productivity can provide further insight into the movement of avian populations among an area, their selection of habitats based upon the NDVI, and how it relates to timing of breeding.

Our findings are important in arid and semiarid environments, where rainfall plays a crucial role in vegetation dynamics [2]. Furthermore, rainfall influences insect diversity [72], seed production [73], seed dispersal [74], and small mammal abundance [75], all of which play an important role in providing resources for the birdlife documented in this study. Initial rainfall conditions can lead to greater biomass production and thus provision of resources for bird species. Subtropical semi-humid-to-semiarid rangelands, such as those described in this study, are more likely to experience annual variation in rainfall events that may impact wildlife populations, and we may continue to see these fluctuations with the added effects of climate change [76].

Our results on a rangeland avian community suggest that rainfall fluctuations that occur in landscapes with extreme weather events lead to results that do not always follow previously supported research [32,33,35]. Rangeland conditions months prior to the start of a biological survey can influence survey outcomes; thus, these conditions should be considered when designing monitoring protocols. The working landscape in this study has a variety of components to it, ranging from cattle production, involving the needs for these animals to graze, raise their young, and live among the elements, to wildlife research and conservation, including capturing, tagging, and monitoring individuals. The coexistence of both must be achieved for the goals of the ranch to be met. Previous research has shown positive impacts on bird populations on such landscapes that implemented rotational grazing and excluded burning as vegetation control [77]. However, this is a challenge considering woody encroachment is becoming an issue on the ranch and has been found to negatively affect grassland birds in these habitats [78]. Prescribed burning is often a strategy used to remove woody plant species but should be used with a combination of land management methods to maintain appropriate cover and resources needed by diverse bird species and other wild and domestic animals [77]. By combining on-the-ground monitoring and the NDVI for land management strategies, these tools can aid in delivering land management recommendations to help sustain avian populations, such as reducing the multi-use aspect of the ranch (i.e., cattle grazing) to provide additional habitat, therefore, vegetation, for birds [51] and improving the availability, distribution, and use of water sources, such as cattle troughs, during below-average rainfall years.

5. Conclusions

Given that avian point-counts are a common monitoring method (particularly with community science initiatives at a national and global scale), it is possible to implement the same methods at a much larger scale since spatial data are now readily available at appropriate resolutions. Remotely sensed information like the NDVI is easily and freely accessible by land managers through online sources such as USGS Earth Explorer (<https://earthexplorer.usgs.gov/> (accessed on 30 December 2024)) and can be used as a tool together with rainfall predictions to aid in finding locations on the landscape that may be higher or lower in vegetation greenness and may or may not be conducive to abundant and potentially diverse bird populations. With this information, management recommendations for restoration of vegetation or other land-altering methods to improve productivity can be

considered. From an economic perspective, knowledge of avian populations and the effects of productivity on the land can assist landowners and managers by ways of ecotourism and hunting leases to identify potential hotspots of wildlife activity. In a working landscape, managers can promote wildlife conservation by identifying times of low bird numbers and species and refine cattle production by adjusting grazing regimes through reduction or rotation of cattle to allow for vegetation to recover to fit the needs for both domestic and wild animals.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/wild2010004/s1>, Table S1: Breeding landbird abundance and richness for May and June and NDVI values for April and May from 2014 to 2016 across 37 point-count stations on the East Foundation's El Sauz Ranch, Texas, USA; Table S2: Bird species detected during breeding bird surveys conducted in May and June 2014–2016 across 37 point-count stations on the East Foundation's El Sauz Ranch, Texas, USA.

Author Contributions: J.L.O. and M.L.L. made substantial contributions to the field-collected data and design. All authors provided important contributions to the spatial data acquisition, design, analysis, and interpretation of the data and provided their input in drafting the manuscript and revising it for intellectual content. J.L.O., M.L.L., A.A.T.C., L.A.B., H.L.P.-B., D.B.W. and T.A.C. have given their final approval of the manuscript version to be published, take public responsibility for appropriate portions of the content, and have agreed to be accountable for all aspects of the work to ensure that all questions related to the accuracy or integrity of any part of the work are investigated and resolved. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The NDVI images used for this study are available through MODIS Terra (MOD13Q1 NDVI) from the United States Geological Survey Earth Explorer (<https://earthexplorer.usgs.gov/>), accessed on 29 October 2024).

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